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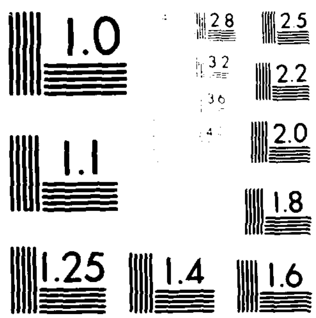
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January 1980

THE VERIFICATION OF FIELDS BASED ON COMPARISON WITH CONCURRENT OBSERVATIONS: THE OPL2X CAPABILITY

by

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By defining hypothetical interrelated distributions of "observed" values, "field" values and "true" values of an arbitrary environmental parameter, it is demonstrated that verification of fields based on comparison with concurrent observations is subject to much misunderstanding and confusion. Conclusions which seem intuitively obvious are often invalid. Biases can be "discovered" which, in fact, do not exist. OPL2X is a soundly-reasoned system for producing valid field verification statistics for both analyzed and forecast fields of a variety of environmental parameters. Examples of the output generated by OPL2X are given.

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1. INTRODUCTION

In March 1978, Meteorology International Incorporated (MII) completed a project [1] on behalf of Fleet Numerical Oceanography Center[1] (FNOC) wherein over 16.5 million synoptic observations made by ships at sea were blended with archived meteorological fields to produce re-analyzed sea-level pressure fields[2] for the Northern Hemisphere on a 63x63 grid (polar stereographic projection). These sea-level pressure fields, covering a period of 30 years (1946-1975) at 6-hourly increments, were used to diagnose sea-level pressure fields for the same times. To check the effectiveness and validity of the MII-developed diagnosis algorithm for use with the re-analyzed pressure fields, a statistical analysis of diagnosed wind speeds versus observed wind speeds was carried out. Two years were selected (1964 and 1965, together representing over 2.3 million wind reports from ships) and actual wind speeds were compared with wind speeds diagnosed from the re-analyzed pressure fields using the wind algorithm.[3] In making the comparison, of course, the diagnosed wind speeds were for the same location as the corresponding reported wind speed. The results were shown in the form of a scatter diagram[4] together with a variety of derived statistics. It was found that there was no overall bias of any significance--in other words, in the mean, observed winds were in agreement with winds diagnosed from analyzed sea-level pressure fields.

These results directly contradicted similar results produced by an FNOC field verification capability known at that time as OPL2[5]; for

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[1]At that time known as Fleet Numerical Weather Central (FNWC).

[2]The analysis system used was an application of the general-purpose Fields by Information Blending (FIB) methodology.

[3]Previous investigations had determined that the MII wind algorithm produced no systematic bias with regard to wind direction.

[4]The scatter diagram arising from the comparison is given later in this Report--see Table 5.

[5]It should be noted that OPL2 was developed for FNOC by another contractor.

example this program usually indicated that diagnosed (and analyzed) winds resulting from applications of FIB methodology were too low when compared with observed winds. Doubt was thrown on the OPL2 field verification scheme. Since OPL2 was being used to "verify" and tune a number of FNOC-produced fields of environmental parameters, both analyzed and forecast, a careful review of the OPL2 program and its results was indicated.

This review was carried out by Holl [2]. By defining hypothetical interrelated distributions of "observed" values, "field" values and "true" values of an arbitrary environmental parameter, Holl clearly demonstrated that verification of fields based on comparison with concurrent observations was (and continues to be) subject to much misunderstanding and confusion. As will be seen, the consequences of Holl's study are far-reaching concerning the subject of field verification statistics and their interpretation.

Having completed the review of OPL2 (which led to a study of field verification statistics in general terms), MII was tasked with programming and implementing a valid field verification capability. This capability, now part of the FNOC system, is known as OPL2X. The current version of OPL2X originally was developed as MII Project Number M-240 [3] and later refined under MII Project Number M-245-08.[1]

It may be noted that even OPL2X results can be misinterpreted if the User has insufficient background knowledge and understanding; conclusions which seem intuitively obvious are often invalid when examined in the light of Holl's study [2]. This Report, produced as part of MII Project Number M-245-08, is intended to provide the User with the necessary insight into the subject of field verification statistics. It gathers together the essential elements of Holl's study (Sections 2 through 5), and describes the capabilities and output of the current version of the OPL2X program for the verification of fields based on comparison with concurrent observations.

[1]Service Order Number QE-08 performed under Contract Number N00228-79-D-9689.

2. BASIC CONSIDERATIONS

2.1 Introduction

The subject fields which are to be verified may have been produced by an analysis capability, or by a parameter diagnosis algorithm, or by a prediction capability. By analysis it is generally implied that the production process includes assimilation of observations which are concurrent with the applicable time range, or time distribution, of the field. The term diagnosis generally implies that no concurrent observations of the object parameter have been directly assimilated in the production of the field. An example is a geostrophic wind field diagnosed entirely from the concurrent surface pressure field. A predicted field generally[1] implies that no concurrent observations of any kind have been assimilated in the production.

A field may be that of a scalar parameter such as significant wave height, or a vector parameter such as a surface wind field. The horizontal wind velocity may be prescribed in terms of two orthogonal components which can be transformed into speed and direction.

A set of observations concurrent with a field (however produced), paired with the set of values specified by the field at the corresponding locations, forms a bivariate distribution. This data set is to be exploited for verifying the field and for evaluating the capability which produced it.

The subject fields which are routinely verified by FNOC include marine wind speed and direction, and significant wave height. The present study is here developed using the wind speed as primary example. However the applicability extends to other fields as well.

It is common to calculate the mean difference and the Root-Mean-Square (RMS) difference between field and observed values as a function of the observed value. That is, the bivariate data set is stratified according to ranges of observed value. These quantities often are interpreted as the average error and the RMS error for each range.

[1] The terms "semi-predicted fields" and "diagnostic-cycle routine" have been used to identify fields of a parameter which are produced with the aid of information in analyzed scenarios of other parameters.

These labels are wrong. The implications are misleading. We shall show that these quantities have little direct bearing on field verification.

2.2 The Objective of a Field

Fields are numerically represented by a finite set of rounded values, together with an interpretation scheme for defining the field continuum from these values. Two types are common:

(1) An array of grid-point values, with grid points referring to uniformly spaced positions over the region of the field, together with a field-interpolation formula or formulas.[1]

(2) A set of values which are interpreted as the combination coefficients of a finite set of component fields defined as being double Fourier Functions of a discrete set of wavelengths, or as some other specified set of functionally-defined elemental fields.

In the present study we will generally have the first type in mind. However the applicability extends to other types as well.

The specification of the field interpretation scheme is often overlooked in the case of grid-point representation of a field; it is left to the User to design his own scheme. This license is bad. Not only may different values be extracted for the same locations but also consistencies between the object field parameter and other fields may be violated in the process. The arbitrary interpolation of ocean parameters should not be allowed at all because continuity in places is interrupted between adjacent grid points. An example of destroying consistencies is the destabilization of static stability in arbitrary interpolation of atmospheric mass-structure parameters.

[1]Fields of ocean parameters, such as Sea-Surface Temperature, produced by the FIB analysis capability are interpreted by one scheme of grid interpolation based on zero-and-first-order continuity in open-sea areas, and by another scheme of grid interpolation in coastal regions where continuity is interrupted by land.

The number of values in the finite set, and their rounding, lower bound the range of scale which may be defined by a numerically-expressed field. A specified time span defines the lower bound of the range of scale in time. The field objective is to specify grid-point values which are representative in that lower-bounded range of scale. A perfect numerically-expressed field defines what we may call the "true" values at the grid points or at any other interpolated location in the field.[1]

What is meant by a representative value in the case, say, of a wind field--a horizontal vector, $\mathbf{V}$, of two components? One often finds this question to be neglected, and field production capabilities are developed without such consideration.

In the context of atmospheric dynamic significance, and operational significance, the usual tacit objective is grid-point values of the wind which are representative of momentum and mass fluxes, usually ignoring the smaller-order horizontal variations in air density. In this context the representative values are those which average-out the subscale. Where several wind observations are available from a very small region relative to the grid array, the average of these winds is the best contributing estimate of the locally representative wind.

There are other objectives in analyzing a wind field. Consider the context of ocean wave generation by wind stress. The emphasis is on field values which are most representative of the effective wind stress in the lower-bounded range of scale afforded by the grid-point array. In this context it is more germane to analyze the field in terms of $V \mathbf{V}$ as object parameter, in components Vu and Vv, where V is the wind speed and u and v are the velocity components.

In combining wind observations in close proximity the combined estimate differs in the two defined contexts. For example, consider three parallel winds of different speeds, say, 10, 11 and 15 units. The

[1] It is very necessary to this discussion to appreciate the differences between an observed value, a field value, a true value and a representative value. In fact many misinterpretations of field verification statistics directly arise from confusing one of these quantities with another. A detailed discussion is provided in Reference [4].

momentum-mean wind speed is 12, and the stress-mean wind speed is the RMS value, closer to 12.2. Additional allowance for gusts, subscale in time to anemometer readings,[1] is also in order in the context of wind stress.

For simplicity we shall proceed with the momentum-wind context, with $\mathbb{V}$ as object parameter. However the study applies equally to the stress-wind context, with $V\,\mathbb{V}$ as object parameter.

It should be clearly understood that a wind observation at a station location is not the same as the field-objective <u>true</u> wind at that location. Contributing variances in observations relative to the true wind include:

(1) Observational errors such as instrument errors and/or errors in subjective estimates.

(2) Subscale variance. This includes the subscale in both space and time.

(3) Gross errors such as errors introduced in transcribing and transmitting observations and their position.

We are primarily concerned with the second of these contributions.

It should also be appreciated that in attempting to verify a field by comparing concurrent observations with corresponding field values, the <u>true</u> value corresponding to each pair is not known. The produced field values <u>are themselves estimates</u> of the field-objective true values.

2.3 A Bivariate Frequency Distribution

Consider the idealized frequency distribution of rounded-value pairs given by Table 1. This sample would apply, for example, to the case in which the observed and the field values have similarly distributed variances relative to the true values, all without bias.

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[1]Wind observations from ships at sea may be based on anemometer readings and/or on subjective estimates based on the character of the wind-blown sea. A skilled observer converts the appearance of the sea into a corresponding, effective stress-mean wind.

Each element of the array gives the number of times, $N_{F,B}$, that the field category, F, occurs paired with the observed category, B. The true value, T, corresponding to each F,B pair is not included. Inclusion of T would require a third dimension for the frequency table of entries $N_{F,B,T}$.

The total number of times that the observed value, B, occurs is given by the column totals, $N_B = \sum_F N_{F,B}$. Similarly the row totals give $N_F = \sum_B N_{F,B}$. The distribution is symmetric about the diagonal. The frequencies favor the lower categories, with the value 2 appearing most often.

We will make use of such frequency tables in several demonstrations.

To each observed category, B, there corresponds a frequency distribution of field values, F. Similarly, a frequency distribution of observed values, B, corresponds to each field category, F.

The mean field value, $\bar{F}_B$, corresponding to an observed value of B is greater than B in the categories B = 0 and 1, equal in 2, and is less than B in categories B = 3 through 9. A verification statistics package based entirely on such stratification may give the misleading label of "field error as a function of observed value" to the difference between $\bar{F}_B$ and B. The implication here is that the field values are too small in the range 3 through 9.

Similar reasoning leads to the opposite conclusion if stratification is based on field value. (Considering that the fields are the products subject to user interpretations and applications this approach seems more appropriate.) The mean observed value, $\bar{B}_F$, corresponding to a field value of F is greater than F in the categories F = 0 and 1, and is less than F in categories F = 3 through 9. The implication now is that the field values are too large[1] in the range 3 through 9!

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[1]The original OPL2 package stratified field values by observed categories. Needless to say, in general it was concluded that field values were too low. Based on this conclusion some numerical models were tuned to remove the non-existent "bias". Had stratification been based on field categories, tuning in the opposite sense would have been required to remove the bias. Both "biases" would have arisen from the same input data.

Table 1
An idealized symmetric bivariate frequency distribution.

Row Total	Field Value										
2	9									1	1
4	8								2	1	1
8	7						1	2	3	2	
9	6					1	2	4	2		
17	5				2	3	9	2	1		
27	4			3	5	15	3	1			
37	3		4	7	19	5	2				
41	2	2	9	20	7	3					
33	1	4	16	9	4						
10	0	4	4	2							
	Observed Value	0	1	2	3	4	5	6	7	8	9
	Column Total	10	33	41	37	27	17	9	8	4	2

Mean values for each class are as follows:

Class:	0	1	2	3	4	5	6	7	8	9
$\bar{F}_B$:	0.8	1.4	2.0	2.8	3.8	4.8	5.8	6.8	7.8	8.5
$\bar{B}_F$:	0.8	1.4	2.0	2.8	3.8	4.8	5.8	6.8	7.8	8.5

We shall demonstrate that neither approach can be interpreted to imply that the field values have been produced with a bias relative to the field-objective true values.

Note that, for the frequency distribution given by Table 1, the overall mean of the difference between observed and field values is zero. That is,

$$\sum_{F,B} N_{F,B} \; (F - B) \quad = \quad 0 \qquad . \tag{1}$$

In fact it follows from the symmetry of the distribution that all moments about the diagonal--the one-to-one relationship--are zero, and the frequency distribution of field values, N_F, is identical to that of observed values, N_B.

3. CONCEPTS AND DEMONSTRATIONS

3.1 A Perfect Field

To explore the properties of bivariate samples we begin with an idealized perfect field. In this example we give the object parameter a preponderance of lower values over higher values. This is characteristic of such fields as wind speed and wave height.

Consider that a large number of observations are clustered around individual field values. The field value of a perfect analysis is the local mean of these observations. Our example is simplified to seven observations per cluster, giving one field value at that location in the object range of scale. (The seven observations can be increased to whatever it takes to create confidence in the corresponding field value.) Observational values have been chosen to give integer mean values. In order to achieve the desired preponderance of lower values, each pair arising from a combination of a cluster of observations with a corresponding field value occurs a specified number of times in the field.

The sample consists of the following:

B Values in Cluster	No. of Such Clusters	Corresponding F Value (= $\bar{B}_F$)	No. of Pairs
6,6,6,7,7,8,9	1	7	7
5,5,5,6,6,7,8	2	6	14
4,4,4,5,5,6,7	4	5	28
3,3,3,4,4,5,6	8	4	56
2,2,2,3,3,4,5	10	3	70
1,1,1,2,2,3,4	11	2	77
0,0,0,1,1,2,3	9	1	63
		Sample Total:	315 Pairs

The corresponding bivariate frequency distribution of 315 pairs is tabulated in Table 2. In this idealized example of a perfect field, field values achieve the desired field-objective true values, i.e., $F \equiv \bar{B}_F \equiv T$. What else can we learn from Table 2?

Table 2
Frequency distribution for an idealized perfect field.

$\bar{B}_F$	N_F	F										
-	0	9										
-	0	8										
7	7	7							3	2	1	1
6	14	6						6	4	2	2	
5	28	5					12	8	4	4		
4	56	4				24	16	8	8			
3	70	3			30	20	10	10				
2	77	2		33	22	11	11					
1	63	1	27	18	9	9						
-	0	0										
		B:	0	1	2	3	4	5	6	7	8	9
		N_B:	27	51	61	64	49	32	19	8	3	1
		$\bar{F}_B$:	1	1.6	2.3	2.9	3.6	4.3	5.1	5.8	6.3	7

The mean field value, $\bar{F}_B$, corresponding to an observed value of B is greater than B in the categories B = 0, 1 and 2, and is less than B in categories B = 3 through 9. Based on this stratification--categories of B--are the field values really biased? Clearly not--we started with a perfect and unbiased field! Stratification of the sample into ranges of B is misleading.

We also note that the frequency distributions N_F and N_B do not match, even for this perfect field. Hence such comparison is not a good indicator for field verification.

The overall (i.e., unstratified) difference between pairs is zero:

$$\sum_{F,B} N_{F,B} \ (F - B) = 0 \quad . \tag{2}$$

The mean squared difference is non-zero:

$$\frac{1}{N} \sum_{F,B} N_{F,B} \ (F - B)^2 = 1.143 \quad . \tag{3}$$

This is the subscale variance in the observations that the field, which is lower bounded in scale, cannot accommodate.

3.2 An Imperfect Field Without Bias

For our second fabrication we modify the preceding example of a perfect field to include variance in the field values, F, relative to the field-objective true values, T. Each cluster of observations is specified to occur four times as often as in the preceding example, with each of the four subsets assuming a field value spread about the true value, spread symmetrically without bias.

The sample consists of the following:

B Values in Cluster	No. of Such Clusters	T Value	F Values	No. of Pairs
6,6,6,7,7,8,9	4 x 1	7	6,7,7,8	28
5,5,5,6,6,7,8	4 x 2	6	5,6,6,7	56
4,4,4,5,5,6,7	4 x 4	5	4,5,5,6	112
3,3,3,4,4,5,6	4 x 8	4	3,4,4,5	224
2,2,2,3,3,4,5	4 x 10	3	2,3,3,4	280
1,1,1,2,2,3,4	4 x 11	2	1,2,2,3	308
0,0,0,1,1,2,3	4 x 9	1	0,1,1,2	252
		Sample Total:		1,260 Pairs

We have constructed a trivariate distribution--trios consisting of an observation, a corresponding field value, and a corresponding true value.[1] The bivariate distribution of observed-and-field pairs is tabulated in Table 3. The bivariate distribution of field-and-true pairs is tabulated in Table 4.

According to Table 3, the mean observed value, $\bar{B}_F$, corresponding to a field value, F, is greater than F in the categories F = 0 and 1, and is less than F in categories F = 3 through 8. Table 4 shows that $\bar{T}_F$ matches $\bar{B}_F$ of Table 3. These resultants cannot be denied; overall, $\bar{B}_F$ is a better approximation of T. Does this imply that the capability which produced the field is biased? Can the field be improved by rescaling F to match $\bar{B}_F$? The answer to both questions is no. Contrary to intuitive reasoning such results do <u>not</u> imply a biased field.

The production capability <u>produced</u> an unbiased distribution of F in each category of true value, T; i.e., $\bar{F}_T$ = T. The bias in $\bar{T}_F$ versus F is a consequence of the frequency distribution of values in the sample. For example, there are 56 cases of the true value 4 which are interpreted by the field as 5's but only 14 cases of the true value 6 are interpreted by the field as 5's. Stratification by field values brings in an unbalanced population of true values.

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[1]This trio is a sample of what occurs in practice; unfortunately the true value is not known. Many field verification schemes <u>assume</u> that observations and true values are one and the same. This entirely invalid assumption produces equally invalid "verification statistics".

Table 3
Frequency distribution of field and observed pairs for a field with unbiased variance relative to true.

$\bar{B}_F$	N_F	F										
-	-	9										
7	7	8							3	2	1	1
6.5	28	7						6	10	6	4	2
5.7	63	6					12	20	15	10	5	1
4.7	126	5				24	40	30	20	10	2	
3.8	210	4			30	68	54	34	20	4		
2.9	273	3		33	82	75	47	28	8			
2.0	287	2	27	84	83	51	32	10				
1.4	203	1	54	69	40	29	11					
1.0	63	0	27	18	9	9						
		B:	0	1	2	3	4	5	6	7	8	9
		N_B:	108	204	244	256	196	128	76	32	12	4
		$\bar{F}_B$:	1.0	1.6	2.3	2.9	3.6	4.3	5.1	5.8	6.3	7

Table 4
Frequency distribution of field and true pairs for a field with unbiased variance relative to true.

$\bar{T}_F$	N_F	F										
-	0	9										
7	7	8								7		
6.5	28	7							14	14		
5.7	63	6						28	28	7		
4.7	126	5					56	56	14			
3.8	210	4				70	112	28				
2.9	273	3			77	140	56					
2.0	287	2		63	154	70						
1.4	203	1		126	77							
1	63	0		63								
		T:	0	1	2	3	4	5	6	7	8	9
		N_T:	0	252	308	280	224	112	56	28	0	0
		$\bar{F}_T$:	-	1	2	3	4	5	6	7	-	-

Figure 1 is a comparison of frequency distributions as function of the value range. Rescaling F to match $\overline{B}_F$ would diminish features in the field continuum. Rescaling would also affect other significant aspects of the field continuum; e.g., gradient would be reduced everywhere.

What other properties does our second bivariate sample have? The overall, i.e., unstratified, difference between pairs is zero:

$$\sum_{F,B} N_{F,B} \; (F - B) \;=\; 0 \quad . \tag{4}$$

The mean squared difference is non-zero:

$$\frac{1}{N} \sum_{F,B} N_{F,B} \; (F - B)^2 \;=\; 1.643 \quad . \tag{5}$$

It should be noted that this variance of field versus observed values is a combination of two contributing, uncorrelated variances: the subscale variance of observed versus true which was calculated in the preceding sample to be 1.143, and the variance of field versus true which is readily calculated to be 0.5. In equation form,

$$\frac{1}{N}\sum_{F,B} N_{F,B} \; (F - B)^2 = \frac{1}{N}\sum_{B,T} N_{B,T} \; (B - T)^2 + \frac{1}{N}\sum_{F,T} N_{F,T}(F - T)^2, \tag{6}$$

for which we can introduce the notation,

$$\sigma^2_{F,B} \;=\; \sigma^2_{B,T} \;+\; \sigma^2_{F,T} \quad . \tag{7}$$

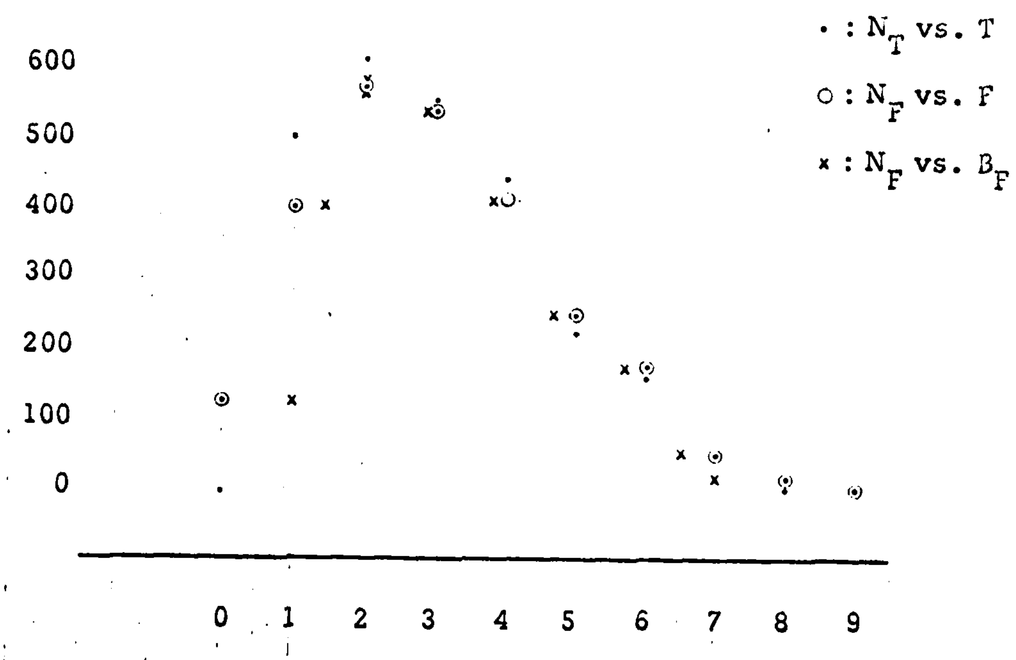

Figure 1 Comparison of frequency distributions. Relative to the other distributions, N_F versus B_F is diminished in the wings of the value range.

3.3 Summary and Conclusions

Our first example, displayed by Table 2, clearly indicates that stratification by observed value, B, is misleading. Our second example, Tables 3 and 4, demonstrates that stratification by field value, F, is also prone to misinterpretation and may lead to abuse of field values by rescaling.

The only stratification which bears directly on the verification of a field, and the evaluation of the capability which produced it, and which gives meaningful resultants, is stratification according to ranges of true value. But the field-objective true values are generally not available.

The above findings do not negate the value of using observations for the verification of fields. Inappropriate stratifications have been indicated (and indicted). Observations are estimates of true. A cluster of observations will tend to resolve local true provided they are sufficiently dispersed in the space and time ambience to be representative of the objective range of scale.

Two additional considerations should be kept in mind:

(1) Observations include variances in addition to the subscale relative to true--instrument/estimation error and transcription/transmission error.

(2) Fields are--should be--produced by exploitation of all available relevant information. The blended resultant of the available information can implicate some individual observations to be grossly in error, or to be non-representative of the objective true value.

4. THE VALUE OF SCATTER DIAGRAMS AND FREQUENCY TABLES

4.1 Inspection

A two-dimensional scatter diagram of the bivariate sample is a plot of points in the coordinate plane of B and F, with each point representing a B,F pair of values. Because of the rounding of values and/or the limitation in the smallness of a plotted point, a multiplicity of points may coincide. This multiplicity can be shown by plotting the multiplicity number instead of a point at the location, and the scatter diagram then becomes a frequency table. A frequency table is, in effect, a coarse scatter diagram. We have shown several artificial examples. Table 5 is a real example taken from a recent MII report [1].

Inspection of such a scatter diagram will tell if anything is very wrong. The experienced eye may be able to pick out some details.

The one-to-one correspondence, the similarity in variances in observed and diagnosed values, and the distribution of values peaking at about 4 or 5 meters/second, are faily obvious in Table 5. At the low end the diagnosed wind speeds are greater than observed, and vice versa at the high end. There is also evidence of a subjective (i.e., observer) preference for the value 15, and against the value 17.

Subscale variance affects the distribution at all ranges. It is an explanation of the relationship at the low and high ends of Table 5.

Stratification of the sample in any category of observed value above 5 meters/second would show the corresponding mean field value to be smaller than the observed value, whereas stratification in any category of field value above 5 meters/second would show the field value to be larger than the corresponding mean observed value. Such stratification is related to fitting a straightline to the data in the "regression" sense, minimizing the mean square distance of all points from the line, measuring distance along one coordinate <u>or</u> the other, depending on which is considered to be the dependent variable.

Table 5
Scatter diagram showing observed wind versus diagnosed wind by class. Numbers on scatter diagram show the lower-bound (in thousands) of occurrences in each class. Over 2.3 million pairs of ship reports and corresponding diagnosed winds were utilized in constructing this scatter diagram.

Diagnosed Wind Speed (meters/second)	0	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20
20																					
19													1			1					
18													1			1					
17										1	1		2			2			1	1	
16										1	1	1	3	1	1	2			1	1	
15								1	1	2	2	1	4	1	1	3	1		1	1	
14							1	1	2	3	3	2	5	2	1	4	1		1	1	
13					1	1	2	2	3	5	5	3	6	2	1	4	1		1	1	
12					1	2	4	4	5	7	7	4	8	3	2	4	1		1		
11			1		3	3	6	6	7	10	9	4	9	3	2	4	1		1		
10			1	1	4	5	9	9	10	13	12	5	10	3	2	4	1				
9	1	1	3	2	8	9	14	14	14	16	14	5	10	3	1	3					
8	1	1	5	4	12	14	20	20	18	18	16	5	9	2	1	2					
7	2	2	8	7	18	21	26	25	21	18	15	5	7	2	1	1					
6	4	5	14	12	26	29	31	28	21	16	13	3	5	1		1					
5	6	7	19	16	31	34	31	27	18	12	9	2	3	1							
4	10	12	28	21	37	37	29	22	13	9	6	1	2								
3	15	18	37	26	37	34	22	16	9	5	3	1	1								
2	18	19	33	21	26	22	13	8	5	2	1										
1	14	14	22	13	15	12	6	4	2	1											
0	2	2	3	2	2	1	1														

Observed Wind Speed (meters/second)

4.2 The One-to-One Relationship

The overall relationship between observed values and field values can be examined by fitting a best straightline to all the points in a scatter diagram. The best straightline is defined as that which minimizes the mean square distance of all the points from the line, measuring the shortest, i.e., line-normal, distances from points to line.

The line can be restricted to pass through the origin, $B = F = 0$. If we define the slope of this line as $\tan\theta \equiv \delta F/\delta B$, then the best fit is given by

$$\tan 2\theta = \frac{2 \sum_{F,B} N_{F,B} \; FB}{\sum_{F,B} N_{F,B} \left(F^2 - B^2\right)} \quad . \tag{8}$$

The formula is more involved if the restriction of passing through the origin is lifted. In the case of Table 4, Eq. (8) gives $\tan\theta = 0.982$.

The best straightline fit, however, does not give specific information as to biases and variances.

4.3 Diagnosis Based on a Model

The frequency distribution, the table of $N_{F,B}$ counts, can be diagnosed in terms of a model to obtain corresponding estimates of the frequency distribution, N_T, the variances $\sigma^2_{B,T}$ and $\sigma^2_{F,T}$, and the bias of F, in each category of true, T. We specify the model by the equations

$B_T = T$

+ a random component normally distributed with a variance which is a function of the category T. (9)

$F_T = T$

+ a bias which is a function of the category T

+ a random component normally distributed with a variance which is a function of the category T. (10)

Negative values of B_T and/or F_T, as given by Eqs. (9) and (10), are to be added to their corresponding positive cells.

In this model there are four unknowns per category T: the frequency, N_T, the normally-distributed variances, $\sigma^2_{B,T}$ and $\sigma^2_{F,T}$, and the bias of F_T relative to T. The frequencies, $N_{F,B}$, are the given resultants, resulting from all categories of T distributed according to Eqs. (9) and (10). In the example of Table 5, there are 20 x 4 unknowns, and 20 x 20 given values of $N_{F,B}$. The objective is to determine a best-fit solution. Let the best fit yield frequency distributions denoted by $N^*_{F,B}$. The best-fit solution is that which minimizes the quantity

$$E \equiv \sum_{F,B} \left(N_{F,B} - N^*_{F,B} \right)^2 \quad . \qquad (11)$$

However development of this diagnosis model lies beyond the scope of the present study.

5. THE FUNDAMENTAL APPROACH TO FIELDS

5.1 Information, and the Quality of Fields

Let us now step back a few more paces in order to take a broad and fundamental view of fields. A numerical field is supposed to represent a composite rendering of all available relevant information. All information stems ultimately from observations.

The information from which a current field may be produced may be classified into three categories according to their time factor relative to the current field:

Source 1: Concurrent observations--observations taken within the applicable time span of the current field.

Source 2: Near-past observations--observations which were taken at times preceding the current field but recently enough to have a direct bearing on the current field. This information can be carried along the time axis, in field form, by extrapolation or prediction techniques, up to the applicable time of the current analysis.

Source 3: Well-past observations. This source is the basis for all types of physical and statistical relationships and other organizations of history. All physical equations establish approximate relationships between parameters, based on past observations of these parameters. In a very true sense a physical equation is a compact representation and essence-extracting distillation of the relationship between all prior observations of the included parameters; as such a physical equation represents information.

The information represented by a field does not just provide an estimate of the absolute value of the object parameter at every point in the field. Resolution of shape parameters, such as gradient, in the field-objective scale of resolution, may be more significant. Shape parameters resolve spatial features; patterns such as troughs may be of the essence. Information for the production of a field also comes in various forms in each of the three source categories cited above. Information comes in the form of estimates of the object parameter at locations in the field, in the

form of gradients and other shape parameters derived from scanning observation systems or from related fields, and in many complex forms. The verification of fields, and the evaluation of production methods, should be concerned with all aspects of field significance--with how well the production capability accommodates each item of assimilated information and with the qualities of the field.

Observations provide estimates of the field-objective true values at scattered locations in the field. Verification often is concerned only with this one aspect of the field. Such verification is incomplete. Observations may conflict with other types of local information assimilated in the production of the field.

Fields should not include extraneous features--features which are unsupported by information. Among several fields which accommodate the total assimilated information equally, that field having the smallest total variability is the superior field.

Predicted fields include no concurrent observations of any type. Diagnosed fields include no direct concurrent observations of the object parameter. Analyzed fields generally include assimilation of some concurrent observations of the object parameter, but additional observations, not available at the time of field production, may later become available for verification purposes. We shall term included observations as dependent, and those not included as independent observations.

An observation may not be representative in the objective range-of-scale of the field. The observation may be non-representative due to the presence of a subscale anomaly in the field. Field analysis capabilities which include observation evaluation functions may reject an observation in producing an analysis for one objective range of scale and may accept the same observation when analyzing to a finer scale for the same subregion. There is a gray zone in which no method can differentiate between an erroneous observation and an observation that has been strongly affected by a subscale feature. The point to note is that individual observations vary in value relative to a field.

5.2 Fields by Information Blending

The Fields by Information Blending (FIB) methodology is based on associating a *reliability* with every item of *information* and with the quantitative assembly and blending of various types of weighted estimates for maximizing the information yield of the field. Details about FIB and its many applications can be found in various reports.[1] Some aspects are particularly relevant in the present context.

The reliability, or weight, of an estimate is defined as the inverse of the variance associated with that estimate relative to the field-objective true value of that estimate. Uncorrelated contributing variances are additive:

$$\sigma^2 = \sigma^2\,(\text{observation}) + \sigma^2\,(\text{subscale}) + \sigma^2\,(\text{transmission}). \quad (12)$$

The subscale variance component is a function of the field-objective lower range of scale.

In specific applications information in a variety of field properties (value, gradient components, etc.) are assembled and blended. Each assembled field property has its own associated weight field (A, B, C, etc.). The blended resultant field also has an associated weight field for each property (A^*, B^*, C^*, etc.); because of economy considerations they are not always computed. But whether or not computed they are defined in association with the product field.

Consider an observation, H_n, with reliability, A_n, which has been included in the assembly and blending. Denote the local field resultant for that property by H^* of reliability A^*. The independent background information for evaluating the observation is given by

$$A_B = A^* - A_n \quad (13)$$

$$H_B = \frac{A^*H^* - A_nH_n}{A_B} \quad . \quad (14)$$

[1]The most complete account to date of a FIB-based analysis system is to be found in Reference [4].

The standard deviation between H_B and H_n is given by

$$\left(A_n^{-1} + A_B^{-1}\right)^{1/2} \quad . \tag{15}$$

We denote the actual difference, expressed in units of the standard deviation, by λ_n:

$$\lambda_n^2 = \frac{\left(H_B - H_n\right)^2}{\left(A_n^{-1} + A_B^{-1}\right)} = \frac{A_n A_B}{A_n + A_B}\left(H_B - H_n\right)^2 \quad . \tag{16}$$

The reevaluation of a report is based on the value of λ_n. If λ_n is less than one, or in the vicinity of one, its weight is left as purported for the class of observations. If λ_n is considerably larger than one the purported weight, A_n, is reduced by proportionate formula to the point of extinction (i.e., report rejection) at the, somewhat arbitrary, value of $\lambda_n = 2.5$. In a normal distribution about 2% of λ_n values exceed 2.5; these are either subscale mavericks or gross errors.

It should be noted that the reevaluation depends on how much independent background information is locally available. For a given absolute difference, $H_B - H_n$, a larger A_B produces a larger λ_n up to the limit of

$$\lambda_n^2 = A_n\left(H_B - H_n\right)^2 \quad . \tag{17}$$

A smaller A_B produces a smaller λ_n down to the limit of $\lambda_n = 0$. The result of the inclusion of this reevaluation process is that isolated observations far removed from any independent conflicting information will be fitted most closely in the absolute sense. The assimilation of all available relevant information in addition to observations of the object parameter will result in the observations being fitted less well in the absolute sense. The conclusion to be drawn from all this is that verification should not be based on any dependent observations--but only on independent observations.

5.3 Verification

If a field has been produced by an application of the FIB methodology then estimates of the associated product reliability fields can be calculated at considerable computational costs. The verification of a field may be intended for the purpose of checking such reliability fields, but, generally, verification is intended to assess field reliability where no associated product reliabilities are available.

Only independent observations of the object parameter should be used to verify a field in the limited absolute sense. Let an observation be denoted by B_n, the corresponding field value by F_n, and the corresponding, but unknown, field-objective true value by T_n. For an adequately large sample the variances are related by Eq. (6):

$$\frac{1}{N}\sum_n \left(F_n - T_n\right)^2 = \frac{1}{N}\sum_n \left(F_n - B_n\right)^2 - \frac{1}{N}\sum_n \left(B_n - T_n\right)^2 \quad . \tag{18}$$

The left-hand side expresses the variance of the field relative to true. The first term on the right-hand side can be evaluated for the sample. The second term can be based on the purported variance of the class of observations relative to the field-objective true values, as expressed by Eq. (12).

6. THE OPL2X VERIFICATION STATISTICS PACKAGE

6.1 Introduction

Study of the literature concerning field verification techniques quickly reveals that little thought has been given to the fundamental questions of what a numerical field actually represents, what constitutes a good field, and how the quality of a numerical field may be judged. As we have seen in previous Sections, lack of appreciation of these issues can lead to "verification schemes" which either are statistically invalid or which produce results prone to misinterpretation. For example a scheme based entirely on stratification of a bivariate sample of observed and field values into categories of observed values produces results which, in a mathematical sense, are correct. The fault occurs when these results are interpreted as evidence of a bias in the field values. It also will be appreciated that use of a regression equation can lead to the discovery of biases which actually are non-existent. Clearly an invalid verification technique (or one for which the results are routinely misinterpreted) is worse than no verification scheme at all.

To carry out field verification in a meaningful and informative manner is not a simple task. Stratification in categories of field value is relevant but, as explained in Section 3, the reults are prone to misinterpretation. The only stratification which gives desired specifics as functions of value is in ranges of true value--but the corresponding true values generally are not available.

Verification actually involves a trivariate distribution. Although the true values corresponding to the bivariate sample of field and observed values are not available they could be diagnosed by a model. Such a model is defined in Section 4.3. The results of the diagnosis would include field bias and variance, and observed variance, in ranges of true value. However the development of the formulation, including a method for solving the resulting system of equations, will not be straightforward. The problem lies in modifying the formulation to make the system at least quasi-linear so that it can be solved iteratively in terms of an inner linear system. Also, the assumption of normally-distributed variance will have to be changed to suit.

At this time development and utilization of a diagnostic model for routine operational use is not recommended. It is doubtful that such diagnosis would generally show enough of interest in the way of peculiarities to warrant the diagnostic computations. Besides being complex and costly it would verify only one aspect of a field--proximity to true--and hence would give that single aspect of field quality total importance. As explained in Section 5 there is much more to a field than mere proximity to the categorical true value, and much more information than recent and current observations should go into the production of a field. At this time diagnostic models are seen as special-purpose programs to be applied to data samples drawn from collections of fields for diagnosis of specific field production capabilities of the diagnostic and prognostic types. For example they may prove very useful for evaluating various types of quasi-geostrophic wind transforms, or ocean-wave generation models.

It is clearly desirable to have a capability for the routine verification of FNOC fields. As explained in Section 4, frequency tables which summarize the bivariate sample are valuable aids to field verification. These tables are useful whether applied to dependent or independent observations--the samples should be clearly distinguished. Note especially that stratification by observed values or by field values should be avoided. The output tables must include cautionary comments with regard to interpretation to prevent the User from "discovering" that field values (and/or observed values) are biased.

The overall mean difference

$$\bar{b} \equiv \frac{1}{N} \sum_n \left(F_n - B_n \right) \quad , \qquad (19)$$

and the variance

$$\sigma^2_{F,B} \equiv \frac{1}{N} \sum_n \left(F_n - B_n \right)^2 \quad . \qquad (20)$$

are very significant in the case of independent observations. According to Eq. (18),

$$\sigma^2_{F,B} = \sigma^2_{F,T} + \sigma^2_{B,T} \quad . \tag{21}$$

Clearly, if a change is made to a field production capability which results in a systematic reduction of the mean difference, $\bar{b}$, and the variance, $\sigma^2_{F,B}$, then that capability has been improved in its ability to approximate the categorical field-objective true values. Note however that the calculated variance, $\sigma^2_{F,B}$, is lower-bounded by the subscale variance, $\sigma^2_{B,T}$, in the limit of a perfect field. The mean difference is a check on the overall bias. The resultants, $\bar{b}$ and $\sigma^2_{F,B}$, may be usefully stratified by geographical regions.

6.2 Outline of the OPL2X Program

The underlying features and capabilities of a soundly-reasoned field verification scheme for FNOC products have been outlined above.

The OPL2X package produces field verification statistics[1] based on comparison with concurrent report values. Bivariate samples of report values, B, paired with the corresponding field values, F, obtained by field interpolation, are prepared, sorted,[2] and analyzed for each field.[3]

The OPL2X package carries out the following analyses of each bivariate data sample:

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[1]Although designed specifically for fields produced by the operational FNOC system, OPL2X is equally applicable (with some program modification) to products generated elsewhere.

[2]In order to remove gross errors and subscale-maverick values from the observations, the sample is sorted on the magnitude $|F - B|$ in decreasing order. A specifiable percentage (e.g., 2%) is withheld from the top of this list.

[3]Wind fields are verified in terms of two scalar components, the wind speed and the wind direction.

a. Compilation of the frequency table of observed (B) and field (F) value pairs.

b. Calculation of row and column frequency totals, mean values and/or mean differences.

c. Calculation of the slope of the best-fit straightline (through the origin) to the sample in the F,B plane.

d. Calculation of the overall mean difference, $\overline{F - B}$, and the variance and/or standard deviation.

e. Stratification of the data sample by latitude zones.

The OPL2X package produces a frequency table based on the scatter diagram of report values, B, versus field values, F, stratified into ranges of B and of F. This stratification of the B,F coordinate plane, illustrated by Fig. 2a, is the basis of several useful row and column summaries. However certain features of the bivariate scatter are not well revealed by this frequency table. The table does not give a clear indication of the difference distribution, F-B.

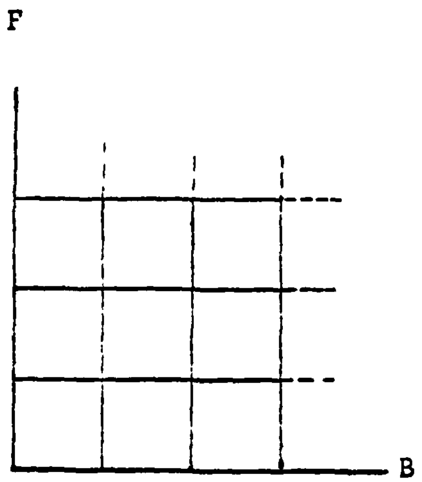

Figure 2a

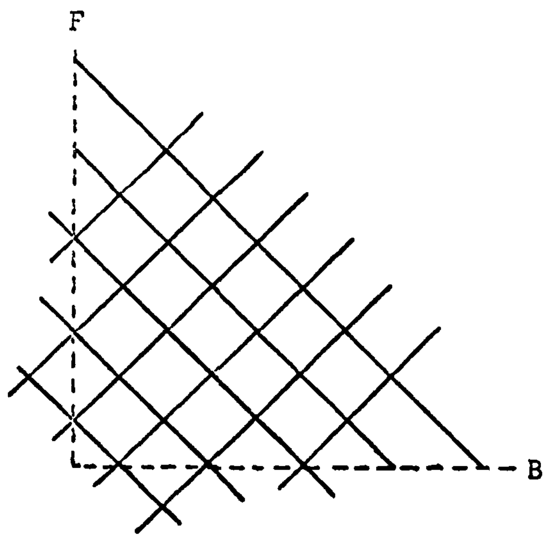

Figure 2b

A second frequency table therefore is provided, based on a different stratification of the B,F coordinate plane, as shown by Fig. 2b. This frequency table is printed in an orientation which represents a 45-degree clockwise rotation of Fig. 2b, with $\frac{1}{2}(F+B)$ as abscissa and (F-B) as ordinate, as shown by Fig. 3. While $\frac{1}{2}(F+B)$ must be stratified to cover the full range of the parameter, the ordinate F-B may be stratified to best reveal the relevant scatter.

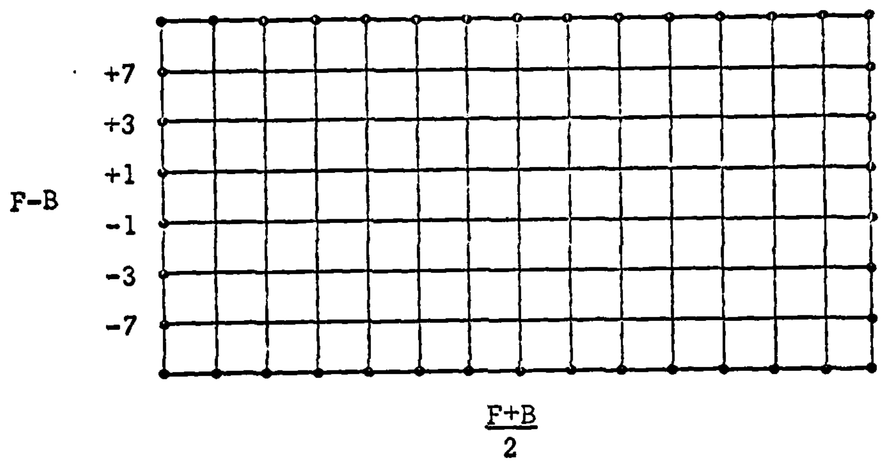

Figure 3

As currently configured, OPL2X can produce verification statistics for the following fields:

a. Wind speed and wind direction.

b. Wave height and wave period.

c. Sea-level pressure.

d. Sea-surface temperature.

OPL2X may be run daily with output directed to fiche for hard-copy retention, and to a disc-resident file for temporary system storage for use in compiling weekly summaries and for other processing. The disc-resident file is circular, holding up to 31 days of data.

On a once-per-week basis the daily run normally is followed by a weekly-summary run,[1] with output directed to printer. The frequency tables represent the accumulated bivariate sample for each field parameter. The daily desiderata--including the mean difference (F-B), mean absolute difference $|F-B|$, the variance, and the straightline-through-origin F/B slope--are listed in individual columns with each row corresponding to each day of the week, producing a table for each field parameter. With each summary run, a Product Interpretation Guide[2] also is output.

In order to facilitate use of the output all necessary information for a complete index in each run of OPL2X is produced as the last part of the output. The index is stored in a form that can optionally be sorted by page number, parameter type, time, or grid region, as desired by the User. More than one type of sorted index may be output in a run.

Other features of the output are apparent from the examples given in the following Section.

6.3 Output Generated by OPL2X

6.3.1 Introduction

This Section provides samples of field verification statistics and other information output by OPL2X. These samples are selected from a daily run made on 08 JAN 80 followed by a summary run.

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[1] Summary runs actually may be produced with any daily run.

[2] See following Section.

6.3.2 Product Interpretation Guide[1]

GENERAL COMMENTS: Concepts relating numerically-expressed fields and concurrent observations have been developed by M. M. Holl. (See, in particular, "The Verification of Fields Based on Comparison with Concurrent Observations (A Critical Review of OPL2)", Meteorology International Incorporated, S. O. 7R-13, Contract Number N00228-78-D-4316, October 1978.) The analyzed verification statistics which follow must be interpreted in terms of such concepts. The statistics are of use in evaluating fields, and the capabilities which produced the fields, in limited senses. The User is cautioned to avoid certain conclusions which may appear at first sight to be intuitive but which are in fact erroneous. Notes to guide interpretations and precautions follow in appropriate contexts.

A numerically-expressed field is an estimate of an objective distribution, the desired "true" distribution, which must be defined in terms of an effective time span for which the distribution is representative, a lower-bounded objective range of scale, and the significant facets of variability. Synoptic observations themselves are representative of subregions in space and time. The field is generally desired for resolution of not only parameter value but also of gradient and other characteristics of shape. Information for resolution of these various facets of the distribution comes in a variety of forms.

Reports, i.e., direct observations and measurements of the object parameter value, estimate only local values of the distribution. These estimates include subscale and error variances relative to objective true value. Further, evaluation of a field using only such reports does not directly assess the resolution of the desired elements of shape in the objective space and time scales.

The concurrent reports which are used to verify a field may be dependent, i.e., they have already been assimilated in the production of the field, or they may be independent of the field. If independent, then it is generally true that the better they match the corresponding field values the better is the field, at least in this one respect. However if dependent then a better match does not necessarily imply a better field;

[1]This Guide normally forms the first part of a summary run. The numbers (1) through (19) in the Guide refer to elements of the output statistics which are correspondingly identified.

resolution of the significant elements of shape may be deteriorated by fitting reports too closely.

Fields may be prognostic (based on prior observations of all kinds expressed in the form of reports and models); diagnosed (based on prior observations and concurrent analyses of related parameters, but excluding concurrent reports of the object parameter); or analyzed (based on all available relevant information including concurrent reports of the object parameter).

Analyzed fields may be verified using dependent concurrent reports but such verification reflects more on the assimilation scheme which produced the field than it does on field evaluation. A well-produced analysis should be an optimized accommodation of all assimilated pieces of information which are related to parameter value and to elements of shape. All pieces of information include variance relative to the objective true distribution. Optimization implies that there are generally many more pieces of information than there are degrees (e.g., number of grid-point values) of accommodation in the numerically-expressed field. It is not generally desirable to minimize residual variance in the accommodation of reports at the expense of increasing residual variances in the accommodation of shape information.

The evaluation of a field requires independent reports. Analyzed fields may be evaluated by using reports which were not made available to the analysis.

The verification statistics are based on limited analysis of bivariate distributions: report values, B, are paired with corresponding field values, F, obtained by field interpolation based on a field interpretation scheme. A third member associated with each pair, but which is generally unknown, is the corresponding true value, T.

The variance of F relative to T would be a measure of the absolute resolution accuracy of the field. Since T is not available, the variance of F relative to B is calculated. The adjusting relationship is:

$$\text{mean square } (F - T) = \text{mean square } (F - B) - \text{mean square } (B - T) .$$

The second term on the right-hand side is the subscale variance which limits the accommodation of reports by the field. The subscale variance

can be estimated for a class of reports and the space and time scales of the field. It is desirable to exclude reports which are in gross error, or appear to be doubtful mavericks, from the above relationship. Such reports should also be rejected by the analysis capability.

THE STATISTICAL ANALYSIS: Bivariate samples of report values, B, and the corresponding field values, F, obtained by field interpolation, are prepared, sorted, and analyzed for each field. Wind fields are verified in terms of two scalar components, the wind speed and the wind direction. The following statistical quantities are calculated for each bivariate sample:

(1) FREQUENCY DISTRIBUTION No. 1:
A table showing the frequency distribution of the bivariate sample according to categories of range. In effect the table is the same as a coarse scatter diagram in the B,F coordinate plane with B, the observed value, as abscissa, and F, the field value, as ordinate. Each element in the body of the table expresses the number of pairs which fell within the range limits of the cell.

(2) - (7) The center values of range intervals are shown along the base (2) for report value; the same ranges are shown to the left (3) of the table for field value. For parameters which are lower bounded at zero (e.g., wind speed) a zero represents a range interval which is half of the others. The frequency distribution of report values is shown (4) below the corresponding ranges. These numbers correspond to the column totals. The frequency distribution of field values is shown (5) to the left of the corresponding ranges. These numbers correspond to the row totals. The mean differences, field minus report, are shown (6) for the range categories of report values. The mean differences, report minus field, are shown (7) for the range categories of field values.

In the case of wind direction, in calculating mean differences, (6) and (7), any pair difference which exceeds +180 degrees is lowered by subtracting 360 degrees, and any

pair difference less than -180 degrees is raised by adding 360 degrees. This reduces the individual differences to the -180 to +180 degree range.

(8) The overall mean difference, i.e., the mean value of (F - B). It should be noted that all differences which exceed a prescribed upper bound in magnitude are omitted from this calculation in order to exclude erroneous reports. This compensates for the fact that gross errors have not been culled from the list of reports.

If the reports are dependent, and if the analysis field is based on assimilation of no other information which bears directly on the value of the parameter, then it would seem reasonable to assume that the field could be improved by subtracting the calculated mean from the field everywhere. This may be appropriate for some analysis capabilities which give all reports equal weight. However a word of caution is in order. Powerful comprehensive analysis capabilities, such as those based on the FIB methodology, reevaluate the individual reports which are assimilated in the analysis process. Those reports which are most at variance with other direct, independent, local information are downweighted in successive refinements of the analysis. This can result in a calculated mean (unweighted) difference which does not represent any possible improvement to the field.

(9) The overall variance, i.e., the mean value of (F - B) squared. Another procedure is followed here to avoid contamination by erroneous reports. The list of differences is first sorted in order of magnitude. A specified percentage of the total number of reports is omitted from the top of this sorted list, and the mean square is calculated for the differences that remain. This calculated mean-square value is then multiplied by an adjustment factor, greater than one, based on a normal distribution, to produce an effective variance.

The interpretation of this calculated variance involves appreciation of the subscale of parameter variability relative to the objective true distribution. The calculated variance is lower bounded by the subscale variance. The calculated variance should be diminished for an analysis which purports to resolve a finer scale.

(10) The slope of the best-fit straightline which also passes through the origin. The overall relationship between observed values and field values can be examined by fitting a best straightline to all the points in a scatter diagram. The frequency table is a coarse version of the scatter diagram. The best straightline is defined as that which minimizes the mean square distance of all the points (the B,F pairs) from the line, measuring the shortest (i.e., line-normal) distance from point to line. The line can also be restricted to pass through the origin, B = F = 0. The tangent (10) of this line is calculated; ideally its value is unity. Disparity from one, however, cannot be directly interpreted in terms of overall bias. The calculation of slope is also not appropriate for wind direction; the origin has no special significance as it does in the case of wind speed or wave height.

(11) FREQUENCY DISTRIBUTION No. 2:
This second tabulation of the bivariate sample gives a clearer representation of the one-to-one relationship between observed and corresponding field values. It results from a 45 degree clockwise rotation of the orientation of the B,F scatter plane on which Table No. 1 is based. The axis of the mean value, (F+B)/2, becomes the abscissa, and the axis of the difference, (F-B), becomes the ordinate. Each of these two axes may be independently scaled into discrete range intervals. Each element in the body of the table expresses the number of pairs which fall within the range limits of the cell.

(12) - (18) The center values of range intervals are shown along the base (12) for mean value, and in the column to the left (13)

for the difference value. For parameters which are lower bounded at zero (e.g., wind speed) a zero represents a range interval which is half of the others. The frequency distribution of mean values is shown (14) below the corresponding ranges. These numbers correspond to the column count totals. The frequency distribution of difference values is shown (15) to the left of the corresponding ranges. These numbers correspond to the row count totals. The mean differences are shown (16) for the ranges of mean value.

INTERPRETATION OF THE TABLE: For the ultimate ideal, all pairs fall into cells lying along the diagonal of the table; all cells not touching the diagonal would be empty. This perfection requires the resolution to be so fine as to make the subscale insignificant. The reports must be representative of the applicable time span, without bias or variance. The field values match the reports, and are the desired objective true values.

In order to appreciate what happens as we leave the ideal it is necessary to note the natural frequency distribution of the object parameter. For example, consider the distribution of the marine wind in equal ranges of wind speed. The frequency peaks at about five meters per second, falling off toward zero and toward higher speed. The frequency distribution for wave height is similar.

Now let a significant subscale enter the picture. Each population center which lies on the diagonal for the ideal distribution is now spread left and right, within each row, in a normal distribution, without bias. Because the spread is symmetrical about the diagonal the mean value for each row remains unchanged: The mean differences (9) remain zero. The field remains true. However the mean differences for the columns (8) are changed because the natural frequencies of occurrence are uneven.

In ranges above the peak occurrence, the column-mean field values show a deficit relative to the observed values in the category range; below the peak a surplus is shown. This result can be entirely attributed to the subscale variance and the natural frequency distribution of the parameter. This evidence alone is insufficient for evaluating the field production

capability. Contrary to earlier versions of OPL2 which labelled these differences as field error they should not be interpreted as such. These mean differences (8) occur even in the case of a field which is true.

Next, introduce variances in the field values relative to the true values, but without bias. Each population center of true values is symmetrically spread out within the column in a normal fashion. The mean differences (9) for categories of field values now become non-zero. The field values show a deficit relative to the observed values in ranges of field values above the naturally occurring most frequent range, and a surplus in ranges below the most frequent. It is wrong to interpret these differences as field biases relative to true. (Reread the first sentence of this paragraph.) It would be damaging to the field to adjust the field values to correspond to mean observed values. While such adjustment would improve the verification of the field relative to observed values, it would not improve the field relative to the desired objective true values. The resolution of extremals in the distribution would especially suffer. Restraint from such actions may be further encouraged by remembering that the field may result from other information, not represented by the verifying reports.

Clearly, if the distribution is concentrated along the diagonal then the field must be good in the sense of high resolution and absolute accuracy. Distributions which are scattered about the diagonal should be examined analytically. The frequency count in any one cell is the result of contributions emanating from sources lying along the diagonal in the ideal case. Does the distribution appear to be consistent with the broadening of the ideal diagonal concentration by the addition of variances alone, or is there evidence of bias in portions of the parameter range? This is difficult to discern; the natural frequency distribution over the range of the physical parameter complicates this analysis. The frequency peaks for an unbiased distribution need not ridge along the diagonal. A capability to perform such an analysis objectively can be formulated but its realization will require a considerable amount of ingenuity and work.

The aforementioned considerations are basic to the interpretation of frequency distribution No. 1--a prerequisite to appreciation of frequency distribution No. 2. This second table is more flexible in that the tabulations are in ranges of difference, and these ranges may be incremented differently from the mean-value ranges. This flexibility is essential for verifying fields of parameters for which differences between observed and field values are generally small relative to the physical range of the parameter (e.g., sea-level pressure, sea-surface temperature). The second table will probably be favored over the first for several reasons. Once understood it is not so likely to mislead. It clearly reveals the correspondence between observed and field values including any inherent biases.

Perhaps the most useful application of the frequency table and related statistics is for comparison of different fields of the same physical parameter, and similar reports, but produced by different capabilities and/or with different resolutions in scale. How do the statistics for a predicted field compare with an analysis of the same field? How do the statistics compare for a coarse grid versus a finer grid? How do changes in a field production capability alter the field verification statistics? How do the statistics compare for an independent sample of reports versus a dependent sample?

(17) DAILY RUN INDEX. Ordinarily this field verification statistics package is to be run once per day. All fields generated in a 24-hour period are available for selection. Each daily run includes an index of the fields verified in the run. This index appears at the end of the output.

MULTI-DAY SUMMARY: Ordinarily the entire output of daily runs is directed to microfiche and is also saved in a circular file which has been set, initially, to hold 7 days of runs but which is adjustable to hold as many as 31 days of runs. The User may request the production of a multi-day summary after any daily run. This supplemental program has been designed to compile the most recent runs held in the circular file; it has been set, initially, to compile up to 7 days of individual runs.

The output of summary runs normally goes to the printer. It begins with a listing of the product interpretation guide.

For each type of processed field held in the circular file the summary program produces frequency distributions No. 1 and No. 2, showing the bivariate distribution which results from combining all available daily runs.

(18) LISTING OF DAILY RUNS. The frequency distributions No. 1 and No. 2 are followed by a list of the individual cases of that field type found in the circular file. In this list each individual case (i.e., single field of the type) occupies a line of output which includes identification and statistical measures (8), (9) and (10) drawn from the daily run of that case.

(19) SUMMARY-RUN INDEX. This index appears at the end of the Summary-run output. It lists in order of appearance the types of fields which have been separately summarized.

6.3.3 Example of Verification Statistics--Daily Run

Table 6 shows OPL2X verification statistics resulting from comparison of field wind directions with wind directions provided by concurrent observations. The field, for 00Z 09 JAN 80, was produced by the FNOC Planetary Boundary Layer (PBL) model on a northern hemisphere 63x63 analysis grid, polar stereographic projection. Corresponding verification statistics for wind speed are shown in Table 7. In both tables, numbers in parentheses refer to those given in the Product Interpretation Guide (Section 6.3.2).

6.3.4 Example of Verification Statistics--Summary Run

Tables 8 and 9 are similar to Tables 6 and 7 respectively but for a 00Z summary run. Although a 7-day summary was specified, for this run the circular file contained only 5 records--i.e., only 5 00Z fields and associated 00Z observations were available when the run was made. The number of records utilized is shown at the top of the tables. As before, the numbers in parentheses refer to those given in the Product Interpretation Guide.

Table 6

VERIFICATION: WIND DIRECTION
DTG: 80013900 ANALYSIS
GRID: 63X63 LAT.BAND: -90.0 --- 90.0
INPUT: F: FIELDS. TYPE: DIAGNOSED SOURCE: PBL
B: SHIP REPORTS. TOTAL NO.REPORTS= 569 ** PARAMETER NAMES: UMAR VMAR

(1) FREQUENCY DISTRIBUTION NO.1. UNITS: DEGREES (0 OUT-OF-RANGE OF TABLE)

(7) B-F MEAN	(5) N	(3) CLASS F												
-2.9	52	330	11	2					1			1	7	30
1.5	80	300	4	2	1				1	2		16	40	14
3.9	44	270	2	1					2	1	5	21	10	2
-14.7	29	240			1		1		2	8	13	2	1	1
-2.3	26	210		1		1	1	2	6	8	3	3	1	
-12.2	24	180			1	2	3	6	5	3	2	1		
-6.3	49	150	2	1	2	1	7	20	11	1		2	1	
2.4	53	120			1	13	21	11	3	1				
-1.6	52	90	1	3	8	28	10	1			1			
-2.4	55	60	1	7	32	5	3	3				1	1	2
-11.1	78	30	13	36	12	5				1	1	2	3	5
-11.4	31	0	14	5								1	2	9
		(2) CLASS B	0	30	60	90	120	150	180	210	240	270	300	330
		(4) N	48	58	58	55	46	43	32	25	25	50	66	63
		(6) F-B MEAN	2.2	-2.3	5.4	6.9	3.3	-2.8	10.2	19.1	-.4	6.5	3.9	3.3

(8) NO. DIFFERENCES (EXCLUDING 31 DIFFS > 30.0): 538. MEAN (F-B)= 1.9 ABSOLUTE MEAN (F-B)=20.0
(9) NO. DIFFERENCES (EXCLUDING 2.0 PERCENT OF LARGEST DIFFS: 558. VARIANCE= 39.61

(11) FREQUENCY DISTRIBUTION NO.2. UNITS: DEGREES (0 OUT-OF-RANGE OF TABLE)

(15) N	(13) CLASS F-B												
1	180											1	
6	150	1		1	2		1				1		
9	120	2				1	1	1		1		1	2
15	90	1	2		2	1	1	1		3	1	1	2
21	60	1	1	2	1	1	2	2	4	1	1	2	3
99	30	11	6	6	13	5	9	4	11	5	9	13	7
302	0	18	40	38	26	28	25	6	7	13	21	42	38
69	-30	7	5	11	5	6	5	7	2	2	2	11	6
31	-60	2		2	3	5	4	2	2	3	1	3	4
11	-90	1		1	1				2		1	2	3
2	-120	1							1				
2	-150						1		1				
1	-180											1	
	(12) CLASS (F+B)/2	0	30	60	90	120	150	180	210	240	270	300	330
	(14) N	45	54	61	53	47	49	23	30	28	37	77	65
	(16) F-B MEAN	10.0	6.0	-.1	9.5	-.3	4.6	4.8	-4.6	12.2	10.2	1.1	.2

** CHECK SOURCE AS TO DEPENDENCE OR INDEPENDENCE OF REPORTS

Table 7

```
VERIFICATION: WIND SPEED
  DTG: 80013000 ANALYSIS
    GPID:NH 63X63      LAT.BAND:  -90.0 ---  90.0
      INPUT:  F: FIELDS,  TYPE: DIAGNOSED    SOURCE: PRL       PARAMETER NAMES: UMAR      VMAR
              B: SHIP REPORTS,  TOTAL NO.REPORTS=   609 **

                          (1)  FREQUENCY DISTRIBUTION NO.1,    UNITS: KNOTS      (  2 OUT-OF-RANGE OF TABLE)
  (7)    (5)   (3)
  B-F     N   CLASS
 MEAN                 F
     I     0    75 .                                                                                     *
     I     0    70 .                                                                               *
     I     0    65 .                                                                         *
     I     0    60 .                                                                   *
     I     0    55 .                                                             *
 -11.?     2    50 .                                           1           1     *
 -17.2     6    45 .                     1     1     1           2     1     *
  -7.5    14    40 .                     1           3     3     5     1     1
  -9.4    29    35 .         2     1     2     1     5    11     6     1
  -2.9    43    30 .               1     5     4    14    13     8     1
   -.9    51    25 .         2     5     3    10    21    19     7     3
  -1.3    93    20 .         2     9    29    34    16     2                 1
   -.3   119    15 .   2     5    32    53    18     6     1     1
   1.4   133    10 .   8    15    57    41     8     2     1     1
   3.5   130     5 .  10    27    45    13     3     1                 1
   5.4     8     0 .   2     1     4     1
                   * . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . *. . B

        (2) CLASS      0     5    10    15    20    25    30    35    40    45    50    55    60    65    70    75
             (6) N    22    54   154   149    79    69    38    31     8     3     0     0     0     0     0     0
    (5) F-B MEAN     7.0   4.4    .8   -.2   -.6    .1   -.4  -2.8 -10.4  -8.7     I     I     I     I     I     I

(8) NO.DIFFERENCES (EXCLUDING  3 DIFFS > 30.0):  606,   MEAN (F-B)=   .4  ABSOLUTE MEAN (F-B)= 4.9
(9) NO. DIFFERENCES (EXCLUDING 2.0 PERCENT OF LARGEST DIFFS:  597,   VARIANCE=  6.95
(10) SLOPE OF BEST-FIT STRAIGHTLINE (F/B) THROUGH ORIGIN:  1.025


                        (11) FREQUENCY DISTRIBUTION NO.2,    UNITS: KNOTS      (  1 OUT-OF-RANGE OF TABLE)
        (15)   (13)
          N   CLASS
                     F-B
          3    30 .                           2           1
          1    27 .                           1
          3    24 .                                 1     1     1
          4    21 .                     2           1     1
          7    18 .                     2     2                 2     1
          9    15 .               2     2     2     2           1
         11    12 .         1           4     2     2     1           1
         27     9 .         7     5     5     3           3     3     1
         63     6 .   3     7    11    17     5    10     6     3           1
        108     3 .   1    15    27    23    18    11     7     5     1
        133     0 .   2    23    42    31    18    15     2     5     1     *     *     *     *     *     *     *
        136    -3 .   1    17    20    27    16    12     7     5     1
         74    -6 .         15    19    18    10     4     8
         29    -9 .          2    10     7     3     1     4     1     1
         11   -12 .                5     1           2     2
          6   -15 .                2     2                 1     1
          1   -18 .                                  1
          3   -21 .                      1     1                 1
          1   -24 .                            1
          0   -27 .
          2   -30 .                            1                             1
                  * . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . (F+B)/2

       (12) CLASS      0     5    10    15    20    25    30    35    40    45    50    55    60    65    70    75
            (14) N     7    87   144   142    95    62    44    28     7     1     1     0     0     0     0     0
   (16) F-B MEAN     2.6    .3  -1.1    .4   1.0   1.3    .9   2.6   4.1   5.0 -89.0     I     I     I     I     I

  ** CHECK SOURCE AS TO DEPENDENCE OR INDEPENDENCE OF REPORTS

FIELD NOT F:N:T:A29          DTG:80013000  -12 HRS
```

Table 8

VERIFICATION: WIND DIRECTION . . . . 7 - DAY SUMMARY . . . . GRID:NH 63X63 5 RECORDS
DTG:800103 TO 800109 00Z ANALYSIS SOURCE:PBL
TOTAL NO.REPORTS= 3330

(1) FREQUENCY DISTRIBUTION NO.1. UNITS: DEGREES (0 OUT-OF-RANGE OF TABLE)

(7) B-F MEAN	(5) N	(3) CLASS F												
-3.3	276	330	30	10	1	4	2	1	3	4	1	14	64	142
-2.9	294	300	8	3	4	1			4	7	8	62	145	52
2.1	163	270	7	2	1		1	1	4	4	23	76	38	6
-2.1	165	240	4		2	1	1	3	18	41	53	24	10	8
.8	203	210	3	3	2	2	3	11	40	92	30	10	4	3
-7.5	243	180	2	1	5	6	13	76	95	30	10	3	2	
-13.5	211	150	5	2	13	18	32	75	52	5		4	1	4
-3.5	200	120	3	2	7	45	84	31	12	3	4	3	2	3
.1	264	90	5	16	56	123	35	11	3	6	4	1	2	2
-8.2	357	60	22	68	174	47	7	8	2	3	2	8	5	11
-4.1	377	30	59	194	62	13	5	2	3	5	4	6	7	16
-4.7	247	0	115	45	7	4	1	3	1	1	2	5	15	48
		(2) CLASS B	0	30	60	90	120	150	180	210	240	270	300	330
		(4) N	263	346	334	255	184	222	237	202	141	216	295	235
		(6) F-B MEAN	5.6	3.7	4.9	2.1	1.5	.7	3.5	.7	-1.9	10.5	7.1	7.6

(11) FREQUENCY DISTRIBUTION NO.2. UNITS: DEGREES (0 OUT-OF-RANGE OF TABLE)

(15) N	(13) CLASS F-B												
12	180	1	2	3				1			1	3	1
32	150	3	2	5	3	4	3		1	1	2	1	7
32	120	6	3	3	1	2	2	1	1	3	2	2	6
73	90	8	13	3	5	6	5	8	1	6	7	4	5
159	60	11	22	14	7	23	10	9	19	5	7	18	14
561	30	53	56	65	49	33	54	35	49	28	44	54	30
1515	0	121	213	191	123	94	89	118	94	61	83	159	172
403	-30	32	46	45	36	26	32	41	23	15	33	40	31
96	-60	7	7	7	9	13	8	6	7	8	7	9	8
49	-90	1	2	6	8	4	4		5	2	6	6	4
38	-120	4	2	1	4	4	5	3	2	2	5	5	1
26	-150	1	3	1	3	4	5	2	3		4		
11	-180			1		2	1	2			1	3	1
	(12) CLASS (F+B)/2	0	30	60	90	120	150	180	210	240	270	300	330
	(14) N	258	355	345	249	215	218	227	205	131	202	304	281
(16)	F-B MEAN	10.3	7.3	5.3	-.5	3.4	-.1	1.8	3.0	6.2	-.4	2.8	8.0

(18) LISTING OF DAILY RUNS. NO.RECORDS= 5

	DAY	VERIFY-HR	FORECAST	GRID	LT.BAND		FIELD	SOURCE	TABLES		FILE-REC	FILE-HR	(8) (F-B)	(8) ABS(F-B)	(9) VARIANCE	(10) SLOPE
1	800103	00Z	0HR	NH 63X63	-90.0	90.0	WIND DIR	PBL	1	2	2	0	4.0	14.9	44.1	
2	800104	00Z	0HR	NH 63X63	-90.0	90.0	WIND DIR	PBL	1	2	14	24	7.9	19.6	35.7	
3	800107	00Z	0HR	NH 63X63	-90.0	90.0	WIND DIR	PBL	1	2	26	96	3.1	20.5	48.2	
4	800108	00Z	0HR	NH 63X63	-90.0	90.0	WIND DIR	PBL	1	2	38	120	3.7	2[illegible]	43.6	
5	800109	00Z	0HR	NH 63X63	-90.0	90.0	WIND DIR	PBL	1	2	50	144	1.9	2[illegible]	39.6	

Table 9

VERIFICATION: WIND SPEED . . . . 7 - DAY SUMMARY . . . . GRID:NH 63X63 5 RECORDS
DTG:800103 TO 800109 00Z ANALYSIS SOURCE:PBL
TOTAL NO.REPORTS= 3221

(1) FREQUENCY DISTRIBUTION NO.1. UNITS: KNOTS (4 OUT-OF-RANGE OF TABLE)

(7) B-F MEAN	(5) N	(3) CLASS F	0	5	10	15	20	25	30	35	40	45	50	55	60	65	70	75
I	0	75																*
I	0	70															*	
I	0	65														*		
-22.0	2	60							1			1			*			
-14.5	9	55					1	2				3	2	*	1			
-14.7	15	50				1		1	2	6	3	1	1					
-9.5	57	45			1	1	1	8	8	12	17	5	1	2	1			
-5.5	98	40			1	4	5	12	19	18	13	11	4		1			
-5.0	166	35	2	2	3	11	12	40	44	29	13	4	3	1	1	1		
-3.0	230	30	2	1	5	21	34	63	51	40	9	4	2	1				
-1.7	337	25	1	8	24	35	69	108	64	17	9		1					
-1.5	490	20	5	15	63	132	159	74	20	8	1	3						
-.1	654	15	13	45	159	254	127	42	8	5	2							
1.3	675	10	34	125	272	165	44	24	4	3	2	2						
3.5	455	5	56	143	172	49	23	9	4		1	1						
3.4	49	0	18	17	10	4												

B

(2) CLASS	0	5	10	15	20	25	30	35	40	45	50	55	60	65	70	75
(4) N	131	353	709	679	475	380	225	139	70	35	14	4	4	1	0	0
(6) F-B MEAN	7.6	3.7	1.5	.4	-.5	-.2	-.7	-2.5	-4.6	-9.0	-9.5	-14.9	-14.5	-31.0	I	I

(11) FREQUENCY DISTRIBUTION NO.2. UNITS: KNOTS (1 OUT-OF-RANGE OF TABLE)

(15) N	(13) CLASS F-B	0	5	10	15	20	25	30	35	40	45	50	55	60	65	70	75
13	30				2	4	1	1	2	2	1						
3	27					1	1	1									
8	24						2	3	2	1							
22	21			2	5	4	5	3	2	1							
34	18			3	9	4	4	3	8	3							
63	15		6	7	8	13	17	4	3	2	2	1					
120	12		11	15	29	16	14	13	12	7	2	1					
191	9		20	42	37	26	19	29	11	6	1	2					
351	6	10	54	69	59	55	44	28	19	5	7	1					
539	3	22	89	124	115	90	46	29	19	7	6		1				
678	0	13	138	184	152	96	63	30	17	12	2	1	*	*	*	*	*
557	-3	4	93	117	147	75	57	31	20	8	5						
322	-6		45	70	82	51	31	24	10	3	4	1	1				
144	-9		5	43	32	24	15	15	5	1	3	1					
69	-12		2	19	16	7	7	5	6	4	1	1					
53	-15			9	16	7	3	7	6	3	2						
20	-18			1	7	5	3	2		1		1					
17	-21				5	3	2	3	2		2						
5	-24					3		1			1						
3	-27				1	1	1										
9	-30					1	4				1	2	1				

(F+B)/2

(12) CLASS	0	5	10	15	20	25	30	35	40	45	50	55	60	65	70	75
(14) N	49	433	703	723	476	339	232	144	66	40	12	3	0	0	0	0
(16) F-B MEAN	2.2	.8	-.0	-.1	.6	1.2	1.5	2.6	3.4	-2.5	-9.4	-17.3	I	I	I	I

(18) LISTING OF DAILY RUNS. NO.RECORDS= 5

	DAY	VERIFY-HR	FORECAST	GRID	LT.BAND		FIELD	SOURCE	TABLES		FILE-REC	FILE-HR	(8) (F-B)	(8) ABS(F-B)	(9) VARIANCE	(10) SLOPE
1	800103	00Z	0HR	NH 63X63	-90.0	90.0	WIND SPD	PBL	1	2	3	0	.9	5.2	7.3	1.020
2	800104	00Z	0HR	NH 63X63	-90.0	90.0	WIND SPD	PBL	1	2	15	24	1.2	5.6	9.0	1.097
3	800107	00Z	0HR	NH 63X63	-90.0	90.0	WIND SPD	PBL	1	2	27	36	-.3	5.2	7.5	.959
4	800108	00Z	0HR	NH 63X63	-90.0	90.0	WIND SPD	PBL	1	2	39	120	.8	5.5	7.8	1.045
5	800109	00Z	0HR	NH 63X63	-90.0	90.0	WIND SPD	PBL	1	2	51	144	.4	4.9	6.9	1.025

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